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Inventors: Shoupu Chen and Lawrence A. Ray
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DIGITAL IMAGE PROCESSING METHOD FOR DETECTING EYES IN AN IMAGE

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DIGITAL IMAGE PROCESSING METHOD AND COMPUTER PROGRAM PRODUCT FOR DETECTING HUMAN IRISES IN AN IMAGE

FIELD OF THE INVENTION

The present invention relates to digital image processing methods for detecting facial features and more particularly to methods of detecting human irises in a digital image.

BACKGROUND OF THE INVENTION

In digital image processing it is often useful to detect human irises in an image. This information is used, for example, to locate other features in the image such as human eyes. This information can also be used for other purposes such as finding the orientation of a human face in the image.

Methods are known in the art for detecting human eyes. For example, U.S. Patent 6,072,892 discloses the use of a thresholding method to detect the position of human eyes in a digital image. In this method, a scanning window scans across the entire image using a raster scanning method. A histogram extractor extracts intensity histograms from the window as it scans across the image. Each intensity histogram is examined by a peak detector to find three peaks in the histogram representing the skin, the white of the eye, and the black of the pupil located within the iris. A histogram having the three peaks identifies a location in an image that potentially defines an eye position. Eye position is determined from among the potential locations by calculating the area under the histogram associated with each potential location and by selecting the location associated with the histogram having the largest area.

One of the problems with this approach is that the entire image must be scanned on a pixel-by-pixel basis. Thus, a search window must be positioned at each pixel and a histogram must be assembled at each pixel location. Further, the area under each histogram must be calculated and stored. It will be appreciated that this method consumes enormous amounts of computing power and reduces the rate at which images can be processed. This method can also produce a high rate of false positives.

Methods are also known to detect eyes that have abnormally high red content. Such abnormal red content is commonly associated with a photographic phenomenon known as red eye. Red eye is typically caused by a flash of light that is reflected by a pupil. As is described in commonly assigned and co-pending U.S. Patent application No. 08/919,560, it is known to search for images for pixels having the high red content that is indicative of red eye. Similarly, commonly assigned U.S. Patent 5,432,863 describes a user interactive method for detecting pixels in an image that have color characteristic of red eye. It will be recognized that these methods detect eyes only where red eye is present.

Thus, there is a need for a method of locating human irises in a digital image that is accurate and efficient.

SUMMARY OF THE INVENTION

The need is met according to the present invention by a digital image processing method for detecting human irises in a digital image. This method comprises the steps of: measuring the red intensity of the pixels in the image, determining the probability that each pixel is an iris based upon the red intensity of the pixel, determining the probability that each pixel is not an iris based upon the red intensity of the pixel; and determining whether the pixel is an iris by analyzing the relationship between the probability that the pixel is an iris and the probability that the pixel is not an iris. In one embodiment of the present invention, the determination as to whether a pixel is an iris pixel is made based upon the application of a Bayes model to the probability that the pixel is an iris, to the probability that the pixel is not an iris, the probability of the occurrence of an iris in the image and probability of the occurrence of a non-iris pixel in the image.

In another embodiment of the present invention, skin color regions are detected in the image and only the pixels within the skin color regions are measured for red intensity. The determination as to whether a pixel is an iris pixel is made based upon the application of a Bayes model to the probability that the pixel is an iris, the probability that the pixel is not an iris, the probability of the occurrence of an iris in the skin color region and the probability of a non-iris in the skin color region.

The need is also met according to the present invention by a method for detecting irises in a digital image comprising the steps of finding an oval shaped skin color region, detecting iris color pixels in the oval shaped region using a Bayes iris model and locating eye positions based upon the detected iris color pixels.

The need is also met according to the present invention by a computer program product for detecting irises in a digital image comprising: a computer readable storage medium having a computer program stored thereon for performing the method of the present invention.

The present invention is effective to obtain iris positions in a frontal face image and has the advantage of reducing the region of the image that must be searched, thereby greatly reducing the computation required to locate an eye, and reducing the incidence of eye detection false positives.

BRIEF DESCRIPTION OF THE DRAWINGS

Figure 1 is a schematic diagram of an image processing system useful in practicing the present invention;

Figure 2 is a flowchart illustrating the eye detection method of the present invention;

Figure 3 is an illustration showing the relationship between certain geometric parameters and an oval shaped skin colored region in an image;

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~~Figure 4 is an illustration showing, the conditional probability that a given pixel is an iris pixel stated as a function of a specific red intensity and the conditional probability that a given pixel is a non-iris pixel as a function of a specific red intensity I.~~

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~~Figure 4a is a flowchart presenting the process of developing a statistical model representing the conditional probability that a given pixel is an iris pixel as a function of a specific red intensity level and the a statistical model representing the conditional probability that a given pixel is an iris pixel as a function of a specific red intensity level.~~

Figure 5 is a flowchart illustrating the process of eye position detection after detecting the iris color pixel clusters;

Figure 6 is an illustration showing the iris color pixel clusters;

Figure 7 is a flowchart illustrating the details of the process of applying the method of summation of squared difference to eye position detection; and

Figure 8 shows an eye template and a search window centered at the center of a cluster.

DETAILED DESCRIPTION OF THE INVENTION

Fig. 1, shows an image processing system useful in practicing the present invention including a color digital image source **10**, such as a film scanner, digital camera, or digital image storage device such as a compact disk drive with a Picture CD. The digital image from the digital image source **10** is provided to an image processor **12**, such as a programmable personal computer, or digital image processing work station such as a Sun Sparc workstation. The image processor **12** may be connected to a CRT display **14**, an operator interface such as a keyboard **16** and a mouse **18**. Image processor **12** is also connected to computer readable storage medium **17**. The image processor **12** transmits processed digital images to an output device **19**. Output device **19** can comprise a hard copy printer, a long-term image storage device, a connection to another processor, or an image telecommunication device connected for example to the internet.

In the following description, a preferred embodiment of the present invention will be described as a method. However, in another preferred embodiment, the present invention comprises a computer program product for detecting human eyes and irises in a digital image in accordance with the method described. In describing the present invention, it should be apparent that the computer program of the present invention can be utilized by any well-known computer system, such as the personal computer of the type shown in Fig. 1. However, many other types of computer systems can be used to execute the computer program of the present invention. Consequently, the computer system will not be discussed in further detail herein.

It will be understood that the computer program product of the present invention may make use of image manipulation algorithms and processes that are well known. Accordingly, the present description will be directed in

particular to those algorithms and processes forming part of, or cooperating more directly with, the method of the present invention. Thus, it will be understood that the computer program product embodiment of the present invention may embody algorithms and processes not specifically shown or described herein that are useful for implementation. Such algorithms and processes are conventional and within the ordinary skill in such arts.

Other aspects of such algorithms and systems, and hardware and/or software for producing and otherwise processing the images involved or co-operating with the computer program product of the present invention, are not specifically shown or described herein and may be selected from such algorithms, systems, hardware, components and elements known in the art.

The computer program for performing the method of the present invention may be stored in a computer readable storage medium. This medium may comprise, for example; magnetic storage media such as a magnetic disk (such as a hard drive or a floppy disk) or magnetic tape; optical storage media such as an optical disc, optical tape, or machine readable bar code; solid state electronic storage devices such as random access memory (RAM), or read only memory (ROM); or any other physical device or medium employed to store a computer program. The computer program for performing the method of the present invention may also be stored on computer readable storage medium that is connected to the image processor by way of the internet or other communication medium. Those skilled in the art will readily recognize that the equivalent of such a computer program product may also be constructed in hardware.

Turning now to Fig. 2, the method of the present invention will be described in greater detail. Fig. 2 is a flow chart illustrating one embodiment of the iris detection method of the present invention. In the embodiment shown in Fig. 2, iris detection is accomplished by first detecting skin colored regions in the image and then identifying iris pixels from the skin colored regions.

The first step in skin color detection is color histogram equalization shown in Fig. 2 as step **22**. Color Histogram Equalization step **22** receives images to be processed and ensures that the images are in a form that will permit skin color detection. This step is made necessary because human skin may take on any

number of colors in an image because of lighting conditions, flash settings or other circumstances. This makes it difficult to automatically detect skin in such images. In Color Histogram Equalization step **22**, a statistical analysis of each image is performed. If the statistical analysis suggests that the image may contain regions of skin that have had their appearance modified by lighting conditions, flash settings or other circumstances then such images are modified so that skin colored regions can be detected.

After the Color Histogram Equalization step **22**, the image is searched for skin color regions in Skin Color Detection step **24**. While it is possible to detect skin in a digital image in a number of ways, a preferred method for detecting skin in a digital image is to separated skin color pixels from other pixels in an image by defining a working color space that contains a range of possible skin colors collected from a large population of images. A pixel is then identified as skin color pixel if the pixel has a color that is within the working color space.

Skin Color Detection step **24** identifies a region of skin color pixels in the image. This region can be defined in any number of ways. In one embodiment, the skin color region is defined by generating a set of pixel locations identifying the pixels in the image having skin colors. In another embodiment, a modified image is generated that contains only skin color pixels. In yet another embodiment, Skin Color Detection step **24** defines boundaries that confine the skin color region in the image. It will be recognized that more than one skin color region can be identified in the image.

Oval Region Extraction step **26** examines the skin color regions detected by the Skin Color Detection step **24** to locate skin color regions that may be indicative of a face. Because the human face has a roughly oval shape, the skin color regions are examined to locate an oval shaped skin color region. When an oval shaped skin color region is found, the Oval Region Extraction step **26** measures the geometric properties of the oval shaped skin color region. The Oval Region Extraction step **26** uses these measurements to define parameters that describe the size of the face and the location of the face within the image.

Fig. 3 is an illustration of the relationship between the geometric parameters used to define an oval shaped skin color region in the image. As is shown in Fig. 3, these parameters include Oval_top **300**, Oval_bottom **302**, Oval_left **304**, Oval_right **306**, Oval_center_row **308**, and Oval_center_column **310**. These parameters are can be used in subsequent processing of the image. It will be recognized that the method of the present invention can be practiced using skin color detection regions that have shapes that are other than oval and that other geometric parameters can be defined in association with such shapes. It will also be recognized that it is not necessary to detect an oval or other shaped area in the image. In such case, the skin color region is examined to detect iris color pixels . Further, in such a case, still other parameters describing the skin color region are defined for use in the eye detection process.

After the oval region extraction has been performed, Iris Color Pixel Detection step **28** examines the pixels in the oval shaped skin color region to detect iris color pixels. In the method of the present invention, Iris Color Pixel Detection step **28** determines whether a pixel is an iris by measuring the red intensity of the pixel. Red intensity levels are measured because it has been observed that that a human iris has a low red intensity level as compared to human skin which has a relatively high red intensity level. However, the method of the present invention does not use a red level thresholding method to determine whether a pixel is to be classified as an iris or as a non-iris.

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Instead, the present invention classifies a pixel as an iris or a non-iris pixel on the basis of a probability analysis. This probability analysis applies an iris statistical model and a non-iris statistical model. The iris statistical model defines the probability that a given pixel is an iris pixel based upon the red intensity level of the pixel. Similarly, the non-iris statistical model defines the probability that a given pixel is not an iris pixel based upon the red intensity level of the pixel. The relationship between these models is non-linear as is shown by way of example in Fig. 4 which is an illustration of the conditional probability 402 that a given pixel is an iris pixel stated as a function of a specific red intensity and the conditional probability 404 that a given pixel is a non-iris pixel as a function of a specific red intensity I.

The probability analysis can take many forms. For example, the probabilities can be combined in various ways with a pixel being classified as an iris or not on the basis of the relationship between these probabilities. However, in a preferred embodiment, a mathematical construct known as a Bayes model is used to combine the probabilities to produce the conditional probability that a pixel having a given red intensity belongs to an iris.

In this embodiment, the Bayes model is applied as follows:

$$P(iris \mid I) = \frac{P(I \mid iris)P(iris)}{P(I \mid iris)P(iris) + P(I \mid noniris)P(noniris)},$$

where $P(iris \mid I)$ is the conditional probability that a given pixel intensity belongs to an iris; $P(I \mid iris)$ is the conditional probability that a given iris pixel has a specific intensity I; $P(iris)$ is the probability of the occurrence of an iris in the face oval region; $P(I \mid noniris)$ is the conditional probability that a given non-iris pixel has a specific intensity I; and $P(noniris)$ is the probability of the occurrence of a non-iris pixel in the face oval region. The Bayes model further applies the probability of the occurrence of an iris in a face oval region and the probability of the occurrence of a non-iris pixel in the face oval region. Using a probability analysis based on the Bayes model, a pixel is classified as an iris if the conditional probability that a pixel having a given red intensity belongs to an iris is greater than, for example, 0.05.

In the embodiment described above, only those pixels in the oval shaped skin color region defined by Oval_top **300**, Oval_bottom **302**, Oval_left 304, and Oval_right **306** are examined. Confining the pixels to be examined to those in the oval shaped skin color region reduces number of pixels to be examined and decreases the likelihood that pixels that are not irises will be classified as such. It will be understood that confining the pixels to be examined to those in the skin color region, as is described in other embodiments of the present invention, conveys similar advantages. It will also be understood that it is not necessary to detect skin color regions and that the present invention can be

practiced by measuring the red intensity of each pixel in the image and determining whether a pixel is an iris based upon the probability analysis described above.

Sub B4 Fig. 4a shows a flow chart illustrating the processes used in the Iris Color/Bayes Model Training step **27** of Fig. 2 for developing the statistical models used to classify the pixels. This step will be performed before the method for detecting irises is used to detect iris pixels. As is shown, a large sample of frontal face images are collected and examined. All iris pixels and non-iris pixels in the face region of each image are then manually identified **40, 42**. Next, the conditional probability that a given iris pixel has a specific red intensity I, $P(I \mid iris)$ is computed and the probability of the occurrence of an iris in the face oval region, $P(iris)$ **44** is computed; then the conditional probability that a given noniris pixel has a specific red intensity I, $P(I \mid noniris)$ is computed and finally the probability of the occurrence of a non-iris pixel in the face oval region, $P(noniris)$ **46** is computed. The computed statistical models of iris and non-iris are used in the Bayes formula to produce the conditional probability that a given pixel intensity belongs to an iris, $P(iris \mid I)$ **48**. In application, the Bayes model can be used to generate a look-up table to be used in Iris Color Pixel Detection step **28.**

The Iris Color Pixel Detection step **28** identifies the location of the iris color pixels in the image. In some cases, it will be desirable to ensure that the iris color pixels that are detected are associated with an eye. This is done by performing the step of eye detection. Eye Position Detection step **27** is used to estimate the eye positions. It will be appreciated that there are many ways to determine whether an iris pixel is associated with an eye in the image. In one preferred embodiment of the present invention, the iris color pixel locations are used to facilitate the process of determining whether an iris pixel is associated with an eye in the image.

Fig. 5 shows a flow chart illustrating the process of eye position detection using the iris color pixels. As is shown in Fig. 5, the eye position detection process starts with an Iris Pixel Clustering step **50**. If iris color pixels

are detected, then the iris pixels must be assigned to a cluster. A cluster is a non-empty set of iris color pixels with the property that any pixel within the cluster is also within a predefined distance to another pixel in the cluster. One example of a predefined distance is one thirtieth of the digital image height. The Iris Pixel Clustering step 50 of Fig. 5 groups iris color pixels into clusters based upon this definition of a cluster. However, it will be understood that pixels may be clustered on the basis of other criteria.

Under certain circumstances, a cluster of pixels may not be valid. Accordingly, the optional step of validating the clusters is shown in Fig. 5 as Cluster Validation step **51**. A cluster may be invalid because, if it contains too many iris color pixels or because the geometric relationship of the pixels in the cluster suggests that the cluster is not indicative of an iris. For example, if the ratio is greater than two, then this cluster is invalid. Invalid iris pixel clusters are removed from further consideration by the method of the present invention. Accordingly, in the portions of the description that follow, valid iris pixel clusters will be referred to simply as iris pixel clusters.

After the clustering operation, a center for each of the clusters is calculated in Cluster Centering step **52**. The center of a cluster is determined as the center of mass of the cluster. The center position of the clusters is calculated with respect to the origin of the image coordinate system. The origin of the image coordinate system for a digital image is defined is at the upper left corner of the image boundary.

Oval division step **54** uses the Oval_center_column **310** parameter to separate the oval shaped skin color region into a left-half region and a right-half region. As is shown in Fig. 6 iris pixel clusters **602** and the center positions 600 of the iris pixel clusters 602 are positioned in either the left-half or right-half regions 604 and 606 separated by the Oval_Center_Column 310.

To locate eyes in the image using the iris pixel clusters, a left-eye position search **56** is conducted in the left-half region using a method known as the Summation of the Squared Difference. A right-eye position search **58** is also conducted in the right-half region based on the same Summation of the Squared Difference method. In general, the summation of the squared difference method

involves calculating the summation of the squared difference of the intensity values of the corresponding pixels in an eye template and a patch of the image that has the same size as the template. In this method, each pixel in the patch of pixels has a corresponding pixel in the template. The difference between the intensity level of each of the corresponding pixels is calculated. Each difference is then squared. The sum of each of the squared differences for each of the pixels in the set is then calculated. This summation of the squared differences provides a relative measure of the degree of correspondence between each of the pixel sets measured and the template. The eye template itself is generated by averaging a large number of sample eye images.

As applied in the present invention, summation of the squared difference values are calculated for each pixel in each window in each half-region. These values are compared and the pixel having the lowest relative summation of the squared difference value is identified as an eye location for the half-region. This process is performed separately on the clusters of the left and the right-half regions of the image in the manner described below.

It will be noted that while the present invention has been described as using the summation of the squared difference method to identify the best relative match between the average eye template and each of the pixels, other methods to determine the degree of relative correspondence can be used. In particular, the mean-squared error method can be used in place of the summation of the squared difference method.

Referring to Figs. 7 and 8, the eye position search process **56** or **58** is started with centering **70** a window **800** at the center of each cluster **802** in a respective half-region. The operation of calculating the summation of the squared differences **72** is then performed, separately, using a patch of pixels centered on each of the pixels in each of windows **74**. The position of the pixel having the lowest summation of squared difference value in each window **800** is recorded **76**. When this process has been completed for every cluster center **802** in a half region **78**, the position of the pixel having the lowest summation of squared difference value is recorded **79**. This position is the eye position for the half-region.

It will be appreciated that the summation of the squared difference method of steps **56** and **58** of Fig. 5, can also be performed without the use of oval region extraction. In such an embodiment, the skin colored region can be divided into a left-half region and a right-half region. Iris pixel clusters can then be divided into left-half region and right-half region clusters. The summation of the squared difference method can then be applied.

The subject matter of the present invention relates to digital image understanding technology, which is understood to mean technology that digitally processes a digital image to recognize and thereby assign useful meaning to human understandable objects, attributes or conditions and then to utilize the results obtained in the further processing of the digital image.

In this manner, the present invention provides an efficient method for detecting normally appearing human irises in a digital image.

The invention has been described in detail with particular reference to certain preferred embodiments thereof, but it will be understood that variations and modifications can be effected within the spirit and scope of the invention.

PARTS LIST

10	digital image source
12	image processor
14	display
16	keyboard
17	computer readable storage medium
18	mouse
19	output device
22	color histogram equalization step
24	skin detection step
26	oval region extraction step
27	iris color Bayes model training step
28	iris color pixel detection step
29	eye position detection step
40	iris pixels
42	non-iris pixels
44	computing step
46	computing step
48	computing step
50	iris pixel clustering step
51	cluster validation step
52	cluster centering step
54	oval division step
56	left eye position search
58	right eye position search
70	window centering
72	summation of squared difference calculation
74	checking step
76	position recording step
78	checking step
79	position recording step
300	Oval_top

302	Oval_bottom
304	Oval_left
306	Oval_right
308	Oval_center_row
310	Oval_center_column
402	probability curve
404	probability curve
600	cluster center
602	iris color pixel
604	left half region
606	right half region
800	a window
802	average eye template moving in window
804	an image
806	average eye template